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Decision Support System for Biebrza National Park

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1. Introduction

A Decision Support System (DSS) was developed in order to quantify environmental changes that occurred during the last two centuries leading to degradation of the wetland ecosystems of the Biebrza National Park. The main idea was bringing together scientific knowledge and practical experience under one framework and subsequently creating and facilitating communication between a network of scientists, nature managers and local stakeholders. As a result, an analysis tool was created, which is used for the description of relations between land use, management activities, surface- and groundwater status, conservation and restoration measures and the current state of wetland ecosystems. The system was built in 2001- 2004 in the framework of a PIN MATRA project by seven Dutch and Polish institutions, then improved in the period 2007-2010 within the cooperation of six Polish and Norwegian institutions with an EEA Grant. The previous stages of the DSS development have been described in several ways (Chormanski & Wassen, 2005; Kardel et al, 2009; Chormanski et al, 2009a).

2. Area

The Biebrza Wetlands are one of the last undisturbed lowland river systems in Europe. The Biebrza River (N.E. Poland) and its riparian areas form a large, fairly pristine inland freshwater wetland. It is a hotspot for biodiversity, which is highly valued for flora, avifauna and mammals (beaver, wolf, otter, elk). Founded in 1992 the Biebrza National Park (BNP) manages a 690 km² area, consisting of 160 thousand parcels (lots; half of them are privately owned). BNP is the largest of the Polish National Parks with the following land cover structure: 43% wetlands, 31% agricultural land (extensive grasslands and pastures) and 26% forests. Several publications have been devoted to the BNP description, the latest data can be found in Wassen et al. (2006).

3. Functioning of the system

The main idea for the development of the DSS for BNP was to centralize and automate the organization, collection and processing of monitoring data in a comprehensive way. The DSS is able to store data collected by permanent and periodical monitoring as well as results of model computations. Thus it improves the analytical process performed by the BNP staff or external users. For achieving these aims two assumptions were made: first, that an input data to the system would be delivered from the different source (e.g. researchers, farmers, tourists, students), and second, that input data would be stored exclusively in one place using Internet. As it is shown on Figure 1, the input to the system consist of:

- data collected by permanent and periodical monitoring conducted by BNP and other institutions;
- reports, questionnaires and random observations of whole groups of system users;
- results of calculation of different models – hydrological, ecological and others which use data from DSS.

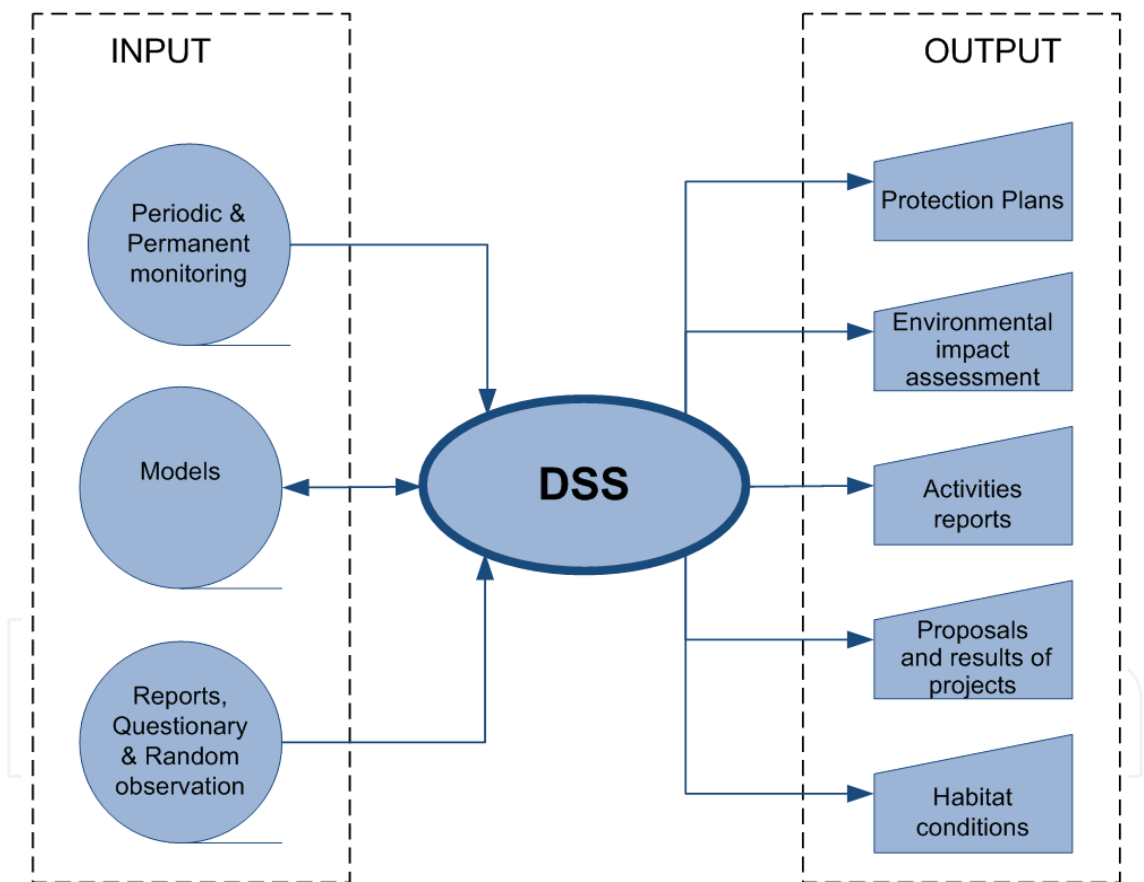


Fig. 1. General system diagram

The main tasks of DSS is verification, formatting, storing, distribution and analyzing of data considering the needs of the specific user. The user needs can be various and the system should provide answers to users in an automatic or manual way depending on a queries status - standard or non-standard. The standard queries are periodic activity reports like: list of protected species or range of protection activities. An automatic process of other nonstandard queries would be conducted depending on the needs of a user. However, it

should be pointed out that most nonstandard queries will be realized manually by using a tool such as ArcGIS Desktop. Actually, the DSS was already used for realizing several queries described in Figure 1 (frame output).

4. Users and beneficiaries

Users of the system are divided into five groups: administrators, staff, scientists, tourists and farmers, which own or rent parcels in the BNP. Additionally, staff members - about 100 people - are divided into eight subgroups (management, accounting, administration, rangers, research, education, library, extension service for farms). Activities of each group emerged from their duties imposed on the employment relationship (staff, administrators), profits (farmers) or interest and knowledge (scientists and tourists). The main activities are listed in the Table 1.

Administrator	Park staff	Scientists & students	Farmers	Tourist
Coordinating declarations of property rights on data	Issue permission on research and land renting	Obtaining the permission for research	Browsing which land can be rented	Maps and photos review
Assignment permission	Input data by Ms Access forms	Download or connect to DSS data	Purchasing the permission on land renting	Excursion planning
Data validation, unification and conversion	Input data by mobile forms	Research planning	Crop and plant quality	Downloading of trails and points of interests
External model & monitoring data collection	Planning	Measurement	Time for field entering	
Backup system	Proposal preparation	Analysis and modeling	Terms of mowing	
Update meta-data	Project realization	Publication	What happens if you stop the mowing?	
	Periodic reports	Send modeling and monitoring results to DSS	Schedule training, meetings, rental of equipment.	

Table 1. Some of DSS users activity

A central unit of the system consists of two computer servers: web server and database server with configuration of Microsoft Windows Server, MS SQL Server, and ArcGIS Server (Fig 2). There are two main applications working parallel on the web server: the first is a geoportal which is working on Apache Tomcad, the second is ArcGIS web map services supported by Internet Information Server.

The Biebrza National Park's Local Area Network (LAN) works in a domain managed by a Microsoft Windows Server setup on second server – called Database Server or Repository. All employees of the park have access to DSS resources in the reading mode. Writing mode

access is given only to specific users who are responsible for particular database updates. Data are entered into the system through MS Access or by ArcGIS Desktop applications. Furthermore, the data are recorded directly in the field on a PDA device with Arc Pad, ArcGIS Mobile or other software.

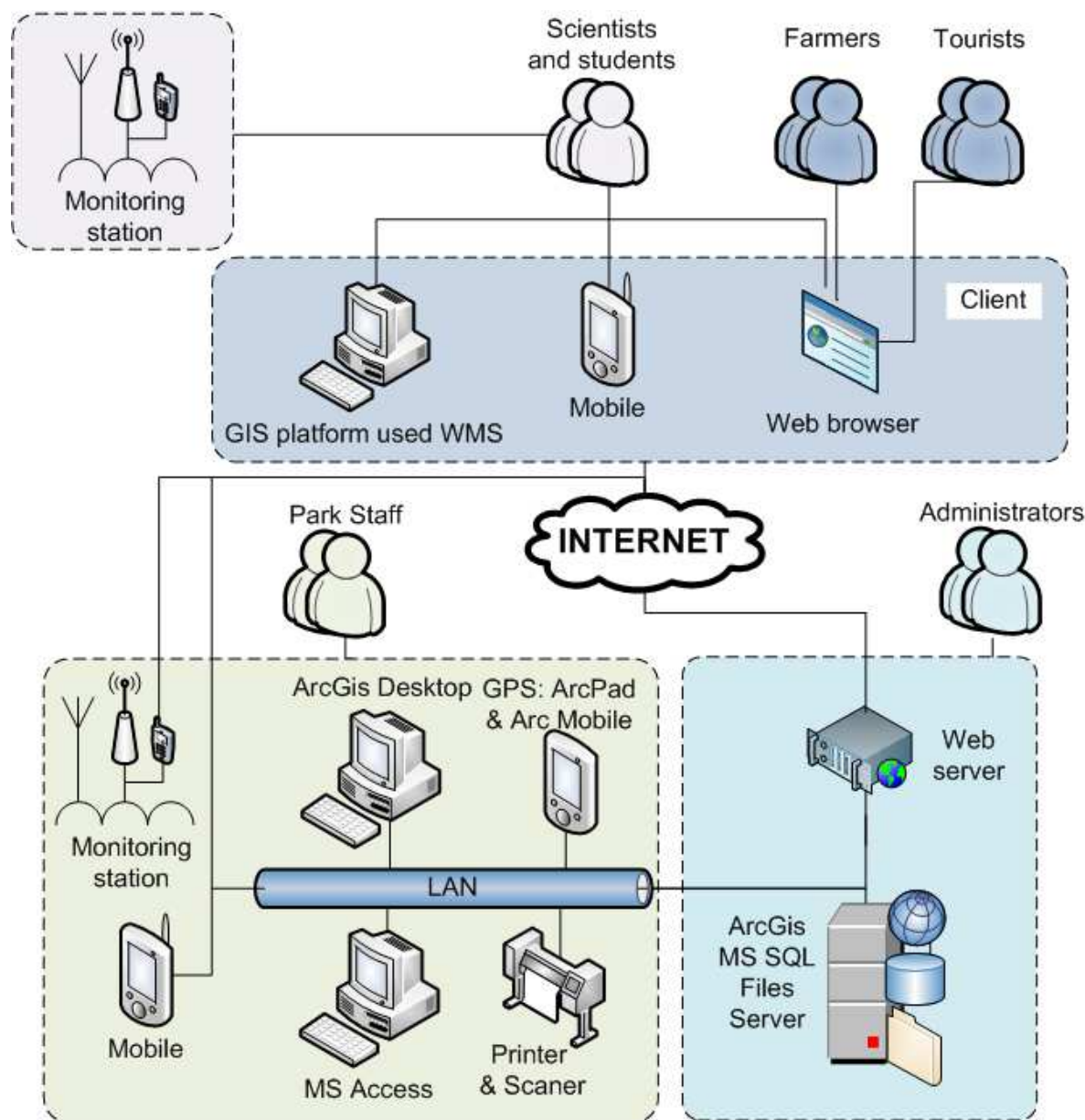


Fig. 2. Communication flow diagram for DSS

The automatic environmental monitoring system which is owned by the Park or by scientific institutions generating continuous time series of data which is stored not directly to the system. Currently, most of these stations, however measured parameters automatically without data transfer to a cellular network due to costs and avoiding the risk of losing data when devices are stolen.

External users can communicate with the system by park staff or by the Internet. Communication over the Internet using three methods: Hypertext Transfer Protocol (HTTP), Web Map Service (WMS) and Mobile Data Service (MDS). HTTP is understood as

applications integrated on Geoportal such as a search metadata or a web map. WMS is understood as a shared map, which can be used by the client's built-in GIS software such as ArcGIS Desktop, Map Info, Quantum GIS. MDS is understood as available maps and forms prepared for mobile devices equipped with GPS receivers and wireless transfer which allows for sending measurement results via the Internet to ArcGIS Server. Moreover, the results of the automatic monitoring stations are sent using the cellular network and the Internet. This method of data communication becomes more important for the system and can be used by workers, scientists and students working with the Park. Data sent by the scientists and student is transferred to a separate database, which checks their legal status, verifies and then introduces information to the main database.

5. Monitoring

Analysis of parameters obtained from water level and discharge monitoring, provide robust and useful information on the physical stage of both water bodies and water-dependent ecosystems. Hydrological and meteorological monitoring has been placed in Biebrza National Park as an activity of special interest, indispensable for effective data-supported management. Collected and processed data of groundwater and surface water level dynamics are frequently applied in decision making processes (i.e. in issuing opinions and evaluating impact of possible investments on ecosystems of the valley of Biebrza). The data obtained from automatic and manual field measurements become also the key input to hydrological models, which broad extent in particular basins of the valley allowed to interpret the status-quo of ecosystems and to analyze certain scenarios of their development in time and space. A hydro-meteorological monitoring network of the BNP was established initially in the very first years of the Park functioning (1990ies) and then extended by different scientific institutes conducting research in the Biebrza wetlands. As hydrological processes play a significant role in the valley of Biebrza for wetland ecosystem development, both surface water and ground water have been continuously monitored since 1995 on numerous locations. The current monitoring network is primarily supervised by the BNP, Institute of Meteorology and Water Management and Warsaw University of Life Sciences staff. It consists of 25 surface water gauges, more than 120 groundwater piezometers, three automatic meteorological stations and four rain gauges. Continuous dataset from monitoring network can be additionally supplied with data collected within the area of BNP by other scientific institutions. The monitoring network of the BNP, Warsaw University of Life Sciences (WULS) and the Institute of Meteorology and Water Management is presented in Figure 3.

Surface water monitoring and the rain gauge standard examination have been done continuously in a 1-day time-interval, however for certain research purposes the surface water network in the lower Basin is running with 6 hours interval, while in upper Biebrza River automatic water level sensors are recording water levels with a 10 minutes interval. Groundwater level measurements are being done in approximately 10-day time interval, however in some locations automatic water level sensors have been installed in piezometers and programmed to a measurement interval of 6 hours. Automatic meteorological stations record parameters of rainfall, wind speed, air humidity, temperature and solar radiation continuously, in 1 – 30 minutes time interval.

Data of hydrological and meteorological monitoring are being collected and delivered to specialists responsible for data processing and storage by field services of the BNP and WULS researchers.

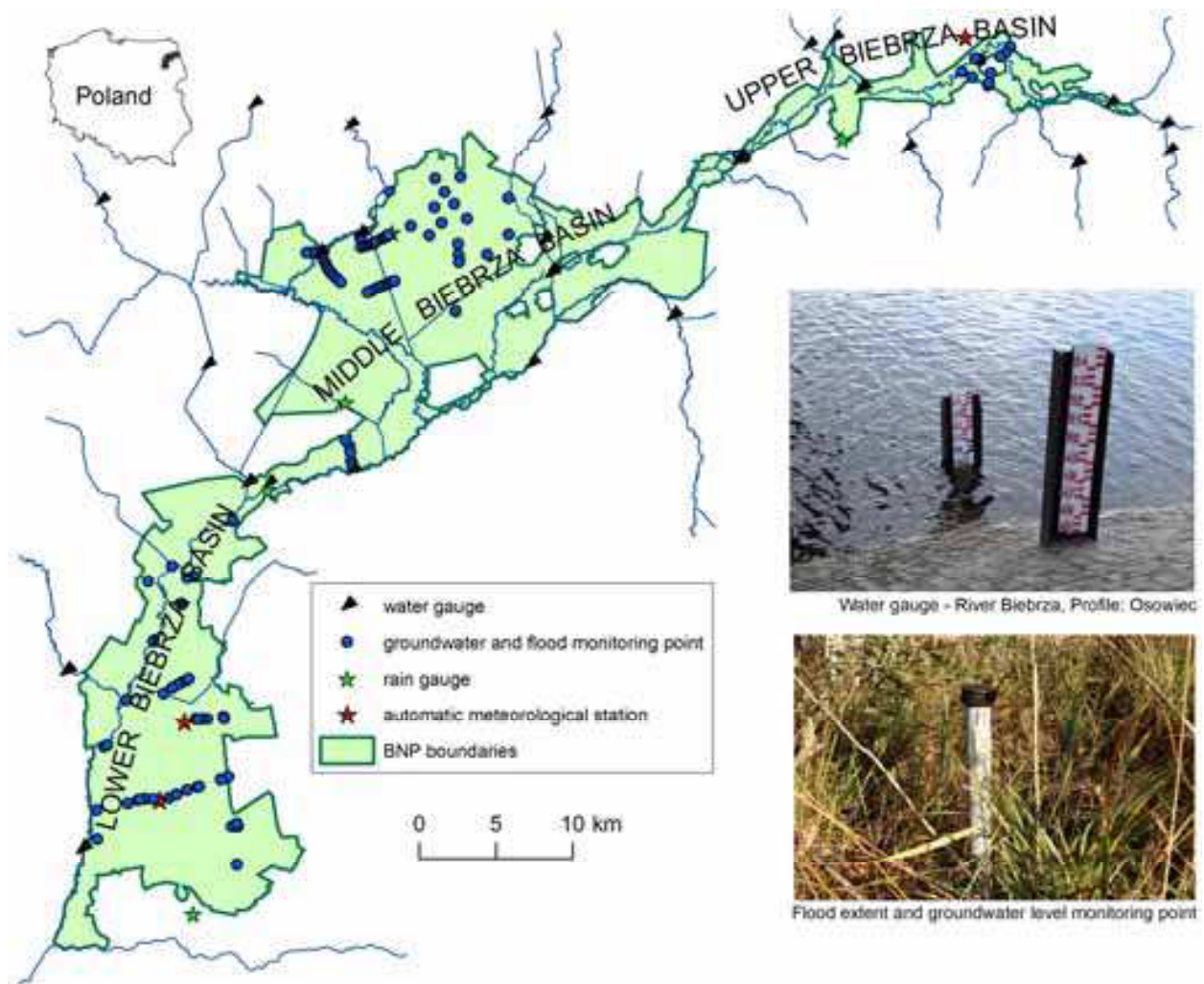


Fig. 3. The hydrological and meteorological monitoring network of the Biebrza National Park

6. Modeling

Within near-natural wetlands of broad spatial extent, most ecological dependencies and management activities are strongly linked to hydrological processes. Among ecosystems of the Biebrza Valley, groundwater discharge-dependent mires and riparian wetlands are dominant types of habitats (Okruszko, 1991). In several parts of the wetlands hydrological information was crucial for the decision on conservation or restoration activities. Therefore, hydrological models have to be set up and aimed to compute either surface-water or groundwater flow dynamics. In this regard, a number of modeling studies were applied in the Biebrza Valley (Batelaan & Kuntohadi, 2002; Grygoruk et al., 2011; Kubrak & Okruszko, 2000; Querner et al., 2010; Swiatek, 2007; Swiatek et al., 2008).

To analyze hydrological processes on groundwater discharge-dependent mires (some) models were set up on the basis of available computation algorithms (SIMGRO, MODFLOW). Hydrodynamic surface-water models (fluviogenic models) are used to analyze hydrological processes on riparian wetlands. Due to the complexity of the problems which were analyzed these models were created and dedicated only to be applied in

particular stretches of the Biebrza Valley. Results of selected modeling approaches were included in the DSS and applied in habitat contiguity and evolution analysis.

6.1 Soligenic mires models structure

To quantify groundwater discharge as a crucial factor for the functioning of groundwater fed mires, the MODFLOW model (McDonald & Harbaugh, 1988) was applied in two separate set-ups: in the Upper Basin (Batelaan & Kuntohadi, 2002; Van Loon *et al.*, 2010) and in the Middle Basin (Okruszko, 2005; Grygoruk *et al.*, 2011). Results of the modeling were analyzed due to habitat contiguity in conditions of various hydrological flow processes and fluxes in the peat soils. Both approaches pay significant attention to groundwater discharge mapping, the crucial factor for the functioning of throughflow mires and their evolution. Groundwater models compute continuous groundwater levels. Applied packages (especially the MODFLOW Drain and Seepage Packages) allowed also to interpret groundwater discharge spatial distribution patterns.

6.2 Fluviogenic wetlands models structure

The state of fluviogenic (riparian) ecosystems is dependent mostly on the conditions of their hydrological alimentation by flooding waters. The most important hydrological characteristics, conditioning of the growth and the development of swamp vegetation, are: inundation surface, mean inundation depth, the frequency and the duration of inundation. A hydrodynamic model coupled with GIS techniques makes it possible to obtain necessary data for the determination of the above-mentioned hydrological characteristics. It is also a tool which facilitates the estimation of the influence of different river valley management methods on hydraulic conditions of water flow. It can even be used as a research tool for executing effective policy of natural values protection within the Biebrza National Park.

Unsteady flow in natural rivers is usually treated as a one-dimensional flow in practice and is based on St Venant equations. In order to simulate flood flow in the lower Biebrza Basin, the one-dimensional unsteady model flow RIVER-SV was applied (Swiatek, 2007). The basic form of the non-linear St Venant equations combined with retention effects of the vegetated areas on flood wave conveyance were used in the model.

The model uses the Darcy-Weisbach relationship for the description of flow rules. It also enables introduction of water mass and momentum exchange processes between the main channel and floodplains, and it has the flexibility to account for parts of a cross section covered with vegetation and those with no vegetation. Thus, the developed model enables accounting for unsteady flow and flow resistance resulting from both vegetation covering a cross section and momentum exchange between the main channel and floodplains.

In the topological discretization scheme of the flow, the Lower Biebrza Basin and its floodplain are represented as a one – dimensional channel from Osowiec gauge to Burzyn gauge. The Wissa River (a tributary) is treated as a point lateral inflow and described by the flow hydrograph at the Czachy gauge. Geometry of the river channel and floodplain is described by 47 river cross sections. The cross sections were measured by manual sounding for the main channel part and the topography of the floodplain was calculated from the Digital Elevation Model. Field monitoring in the Lower Biebrza Basin proves that during flood periods, the river valley consists of parts which mainly act as storage for flood water and of active flow areas (Chormanski and Mirosław-Swiatek 2006). The 1D model is capable of describing flood conditions using the appropriate geometry of cross-sections, which are limited to the active flow zones. In the developed model, the particular areas for each cross-

section were identified according to a vegetation map and topography determined with the Digital Elevation Model (DEM). The Lower Biebrza Basin model was successfully calibrated and verified for the measured data and historical data of flood events (Swiatek et al., 2008). The water level values calculated with the numerical model of flood-flow for cross-sections were used to determine the digital model of the floodwater table in the valley. Then, flood extent maps were calculated for the whole area of the valley by overlaying the DEM and water table layers.

7. IT components

Due to a historical legacy of the system, it is partly based on the relational databases (MS Access) which is converted as necessary to the Environmental Systems Research Institute (ESRI) geodatabase format. In addition, due to the low bandwidth Internet Web Server, the Park has been tested and exhibited outside its headquarters on the server at the Warsaw University of Life Sciences – SGGW (WULS). The system was tested in the BNP with particular reference to the Red Bog Reserve (a raised bog area located in the northern part of the Middle Basin) .

7.1 Databases and maps

The system consists of ten thematic databases built in a client-server structure. The database tables are located on the server while the forms are on the personal computers of individual staff. Each database is built, or is combined with a layer of information in a shp format or geodatabase by ESRI. The whole system uses software MS SQL Server, MS Access and ArcGIS Editor. The thematic databases contain information gathered from different research activities conducted since the establishment of BNP in 1993, biota and a biotic resources inventory, which was done during BNP management plan development in the late 1990ies as well as historical and current management practices recorded by the park staff.

In the system the following database are included (Chormanski & Wassen, 2005):

- Ownership database

This database contains information on parcels situated within the BPN area. Information on owners, usage and territorial units (commune, districts) is kept for each parcel.

- Non-Forest Management Activities database

This database is adapted for storing information on performed and planned protective treatments.

- Forests database

This database is adapted for storing information on forest sub-sections within the BPN area. It contains particularly information on general characteristics of more than 4400 forest sub-sections, forest valuation description, information on gaps, planned and performed protective and growing treatments, and on cuttings.

- Fauna database

This database is adapted for storing information on location, number and living environment of vertebrates and invertebrates. It contains also characteristics of species as far as relation to the human kind, zoography and ecological classification is concerned.

- Flora database

This database is adapted for storing information on occurrence and characteristics of plant species, as well as on planned and performed protective treatments.

- Water quality database

This database is adapted for storing information on location and chemical and physical properties of tested water taken from ground bore-holes, as well as from lakes and rivers. It generally contains data from the area of BPN and from its protection zone.

- **Pollution database**

This database is adapted for storing information related to observation of the following types of pollution: surface water pollution (direct sewage discharges), groundwater pollution (waste dumps, fertilization, dunghills), air pollution, extra-ordinary environmental hazards.

- **Hydrology & Meteorology database**

This database is adapted for storing information related to the following observations made at piezometers, gauge stations and weather stations: location, levels of surface water and groundwater, discharge of surface water, precipitation quantity, air temperature and other meteorological data.

- **Soils database**

This database is adapted for storing historical information on the following observations from soil pits, as well as cyclical surveys of physical and chemical properties of soil at various depths. It particularly contains: location, plant coverage, depth to water surface, characteristic of soil layers, general soil type, physical and chemical properties of soil.

- **Fires database**

This database is adapted for storing information on location of fires, causes for their occurrence, duration, number and type of fire brigades participating in extinguishing them, character and costs of damages caused by fire.

7.2 Mobile application

To improve the data collection process in DSS, recently mobile applications were developed. These applications have been successfully tested by researchers in extreme conditions of remote area, so that, after positive experience, they were distributed to the staff of the BNP. Four mobile applications have been developed: a “piezometer”, “soil pit”, “fauna observation” and “phytosociological photo”. The task of “piezometer” application is to record water level and physico-chemical parameters of water taken at different levels, i.e.: pH, electro conductivity, temperature. However, “soil pit” application is designed to describe the habitat in the individual soil layers. It consists of a series of subforms describing in turn: place and time of observation, layer (thickness and type of soil) other physico-chemical soil parameters. Both applications were developed using ArcPad Application Builder and work in an environment of ArcPad (Fig. 4). After testing these applications, it became clear that ArcPad because of its numerous functions is complicated to use for ordinary BPN staff without specialized training. Therefore, other applications were developed in an ArcGIS Mobile (Fig. 5). “Fauna observation” application consists of one form of recording: who, where, when saw a particular animal species, in which number and which behavior. “Phytosociological photo” application consists of two forms of registration: who, where, when and as a second: in what plant community was the observation and counting performed and description of plant species. The advantage of ArcGIS Mobile application is its full integration with ArcGIS Server, which enables anywhere, anytime, to download the current state of the database of maps and forms over the Internet and in the same way to send the work on the server. This application consists of five tabs Map View, Collect Features, Search Features, View Work List, Synchronize, the corresponding status in accordance with their name on various activities.

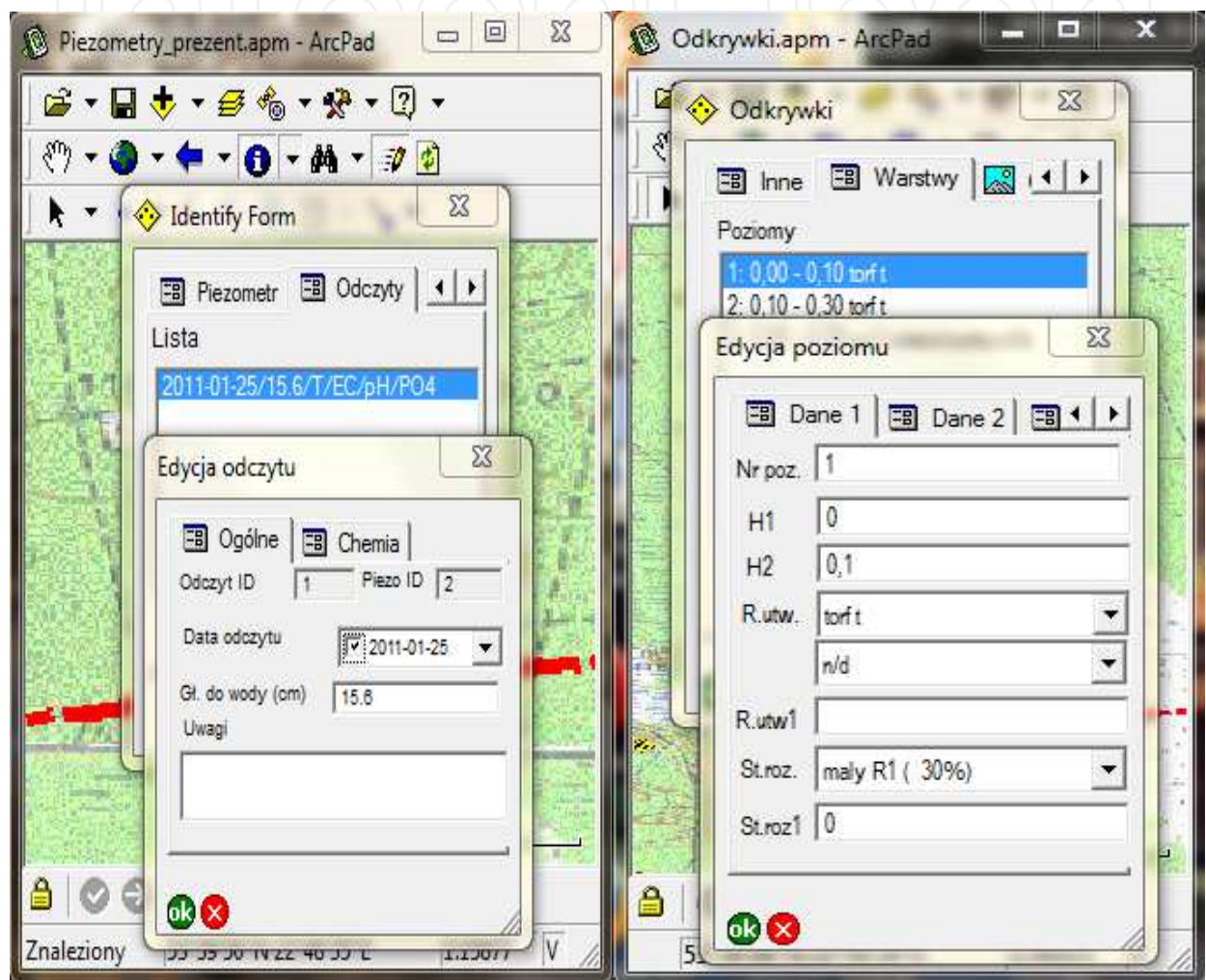


Fig. 4. “Piezometer“ (on left) and “soil pit “ (on right) forms run on ArcPad environment



Fig. 5. “Fauna observation“ (on left) and “phytosociological photo“ (on right) forms run on ArcGIS Mobile environment

7.3 Geoportal

From the outside user point of view the most useful tool is the geoportal, installed temporarily at http://levis-map.sggw.pl/geoportal_biebrza. This tool was created based on ESRI's product called Geoportal Extension cooperating closely with ArcGIS Server (ESRI, 2011). It is divided into five tabs: home, search (Fig. 6), browse, download, interactive map (Fig. 7) all prepared in two language versions (Polish and English). Data can be viewed in a thematic directory, located in the Browse tab. The Download tab is used to send data from selected areas by mail. However the Interactive Map tab allows to view resources, which includes information about location and basic characteristics for particular research. This tab also provides access to photographic documentation (in the format 3-D) of the studies carried out in strict nature reserves, inaccessible for tourists. Additionally the portal has functions of registration for new users, which extends their rights for input description (metadata) of the research carried on the area of BNP. To the special features of this webpage, one can edit and search the metadata in a format compatible with the European Commission (EC) INSPIRE Directive (EC, 2007). Future plans for the geoportal is to add two new tabs: Mobile Applications and Scenario. The Mobile Applications will be used to download on PDA forms while the Scenario tab will querying the system in order to obtain answers to various scenarios.

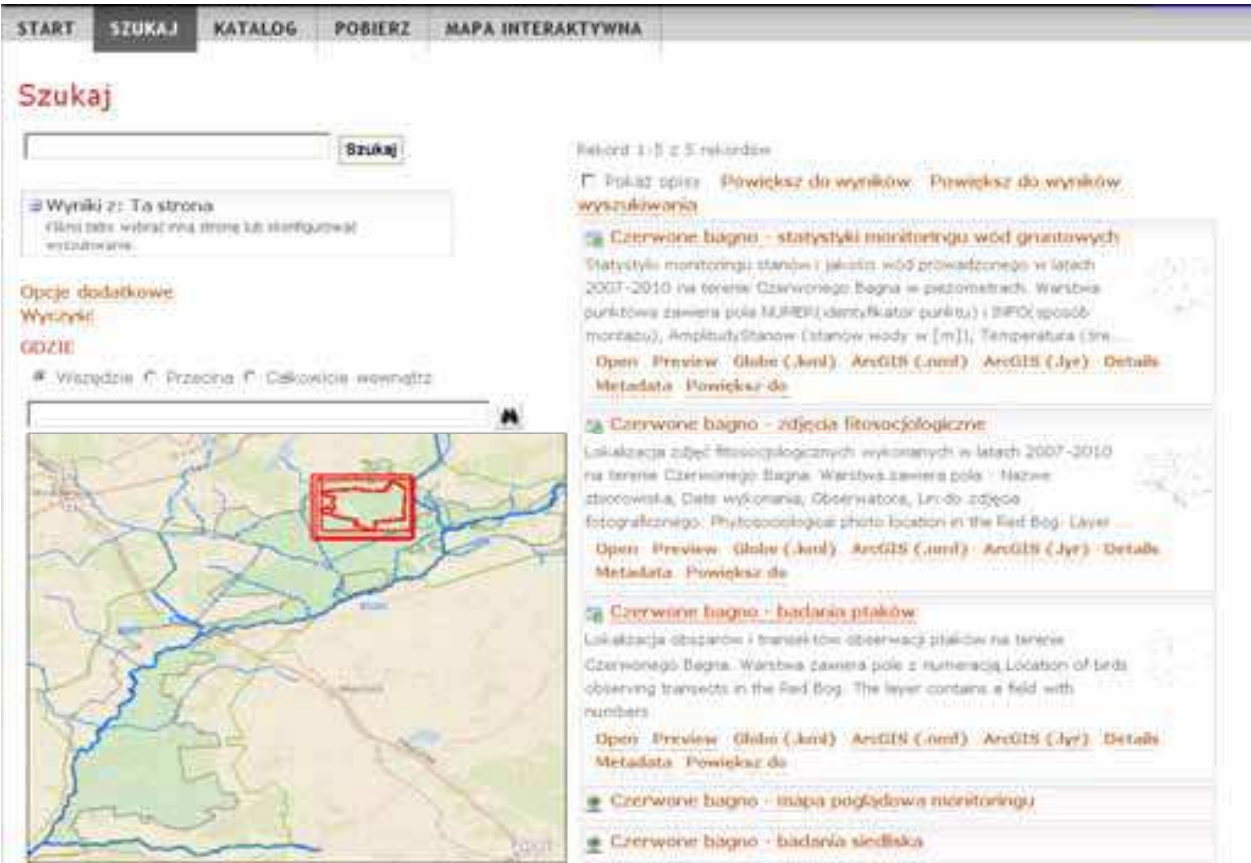


Fig. 6. Geoportal search metadata tab

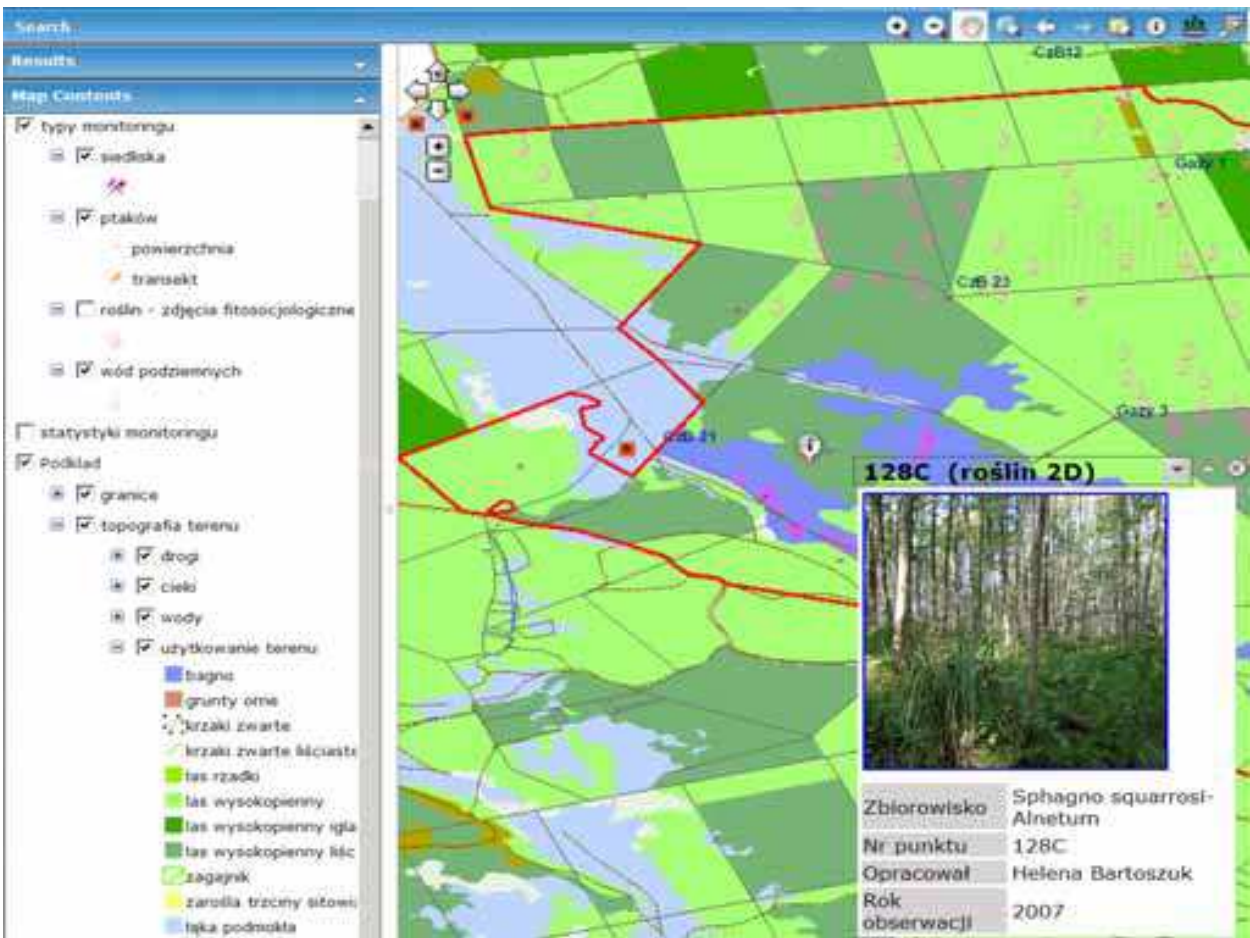


Fig. 7. Geoportal interactive maps tab

8. Stages of system development

The construction of DSS was done in a few phases: retrieving the existing data, designing the system, programming, testing and users training. The detailed scope of the work can be described as follows:

- construction of the system structure, purchase of hardware and software necessary for installation of DSS,
- creation from scratch of 10 thematic databases and five in the form of geodatabases,
- conversion of the existing descriptive and map data to databases,
- conducting field studies to identify the parameters of the models,
- simulations of several scenarios developed in Hydrological and Ecological Modules,
- training of employees appointed to use the system,
- developing, training mobile applications for data input,
- testing the applications in the field,
- development of web maps and web data access page.

9. Results

Already several studies were conducted with the assistance of the DSS. Most of them were site specific and problem oriented. The results obtained during these studies, when stored

and processed in the DSS can be of use also for other types of studies which are or will be needed for wetland ecosystem conservation or restoration, if these do not require the need to re-run models, since this is often not user friendly or requires the authors (developers) assistance. The examples given below show a range of results possibly to be obtained from different sources.

9.1 Soligenic mires models results

Results of the reference model runs as well as runs that include the input data of hydrological stress caused by human and natural impacts, are stored as raster and vector files, which make them ready to use from the level of database in GIS. Depending on actual needs and situation, new model runs can be done and analyzed as some elaborated and calibrated computation algorithms are also stored in the database. Continuity and ecological function stability of wetlands in the Middle Biebrza Basin are strongly dependent on minerotrophic groundwater discharge from the sandy aquifer to superficial layers of peat. Common balance between lateral groundwater inflow and accumulation of precipitation water on top of the peatland is responsible for the development of transitional mires. Modelling of groundwater discharge in various hydrological scenarios, that include increased groundwater inflow to the valley from adjacent plateaus (Fig. 8), can become an important verification of management strategies held by the BNP authorities. The relevance of such a modelling study increases, if a complex set of different restoration strategies needs to be evaluated. Then, some hydrological indicators that become the main force for wetland development, can be visualized and analyzed in coherence with other aspects, that particular strategy should have fulfilled.

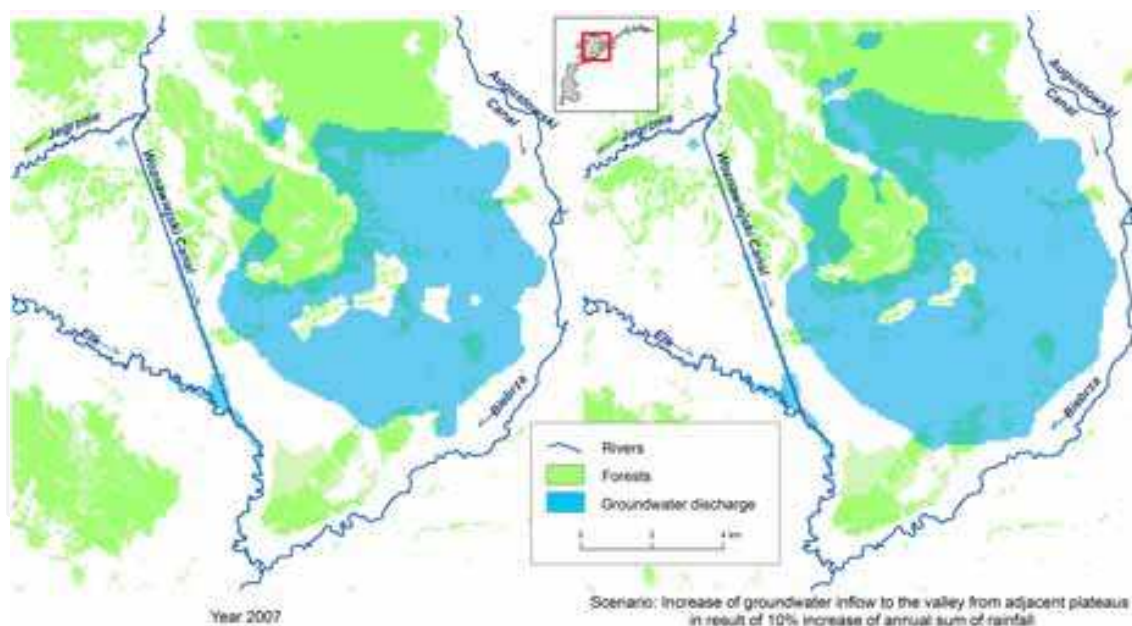


Fig. 8. Results of the steady-state groundwater discharge modelling – comparison of hydrological conditions in Middle Biebrza Basin in 2007 and in a scenario, that assumes 10% increase of groundwater inflow to the Biebrza Valley from adjacent plateaus.

9.2 Fluviogenic wetlands models results

This procedure allows for flood simulations with the hydrodynamic model and GIS analysis for determinations of inundation extent and was used for elaboration of different kind of

maps, used in the DSS system (Fig.9). This type of performance combined with the physical and chemical studies of water are the basis for the analysis of biodiversity in wetland areas.

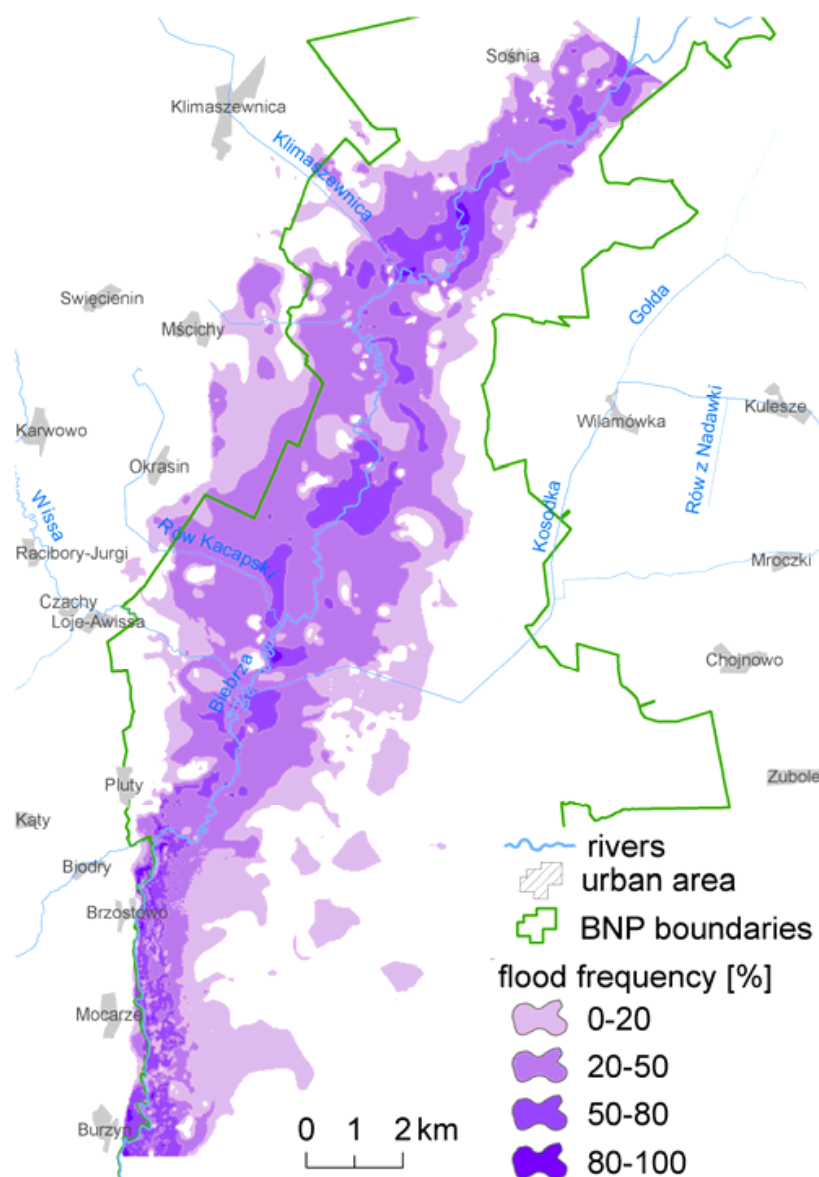


Fig. 9. Example of fluviogenic model results presenting of long-term annual mean flood frequency on Biebrza Lower Basin in the vegetation season (February-September) in the period 1961 till 1996 (Chormanski et al., 2009b)

9.3 Geostatic relationship of hydrology and ecology in riparian wetlands

The main purpose defined for the surface water flow model has been to generate suitable hydrological data for the ecological module and the data for producing thematic maps with the range of flooding for the DSS module. The long term flood characteristics are very important for ecosystem development. Chormanski et al. (2011) described significant relations between the distribution of plant communities and the extent of average floods, which could be considered as long term average inundation conditions. One of the practical

applications of the DSS is analysis of the spatial relation between flood's statistic maps and vegetation maps. The analysis is performed in ArcGIS. It shows strong relations between inundation frequency maps and different water dependence classes of ecosystems in the Biebrza Lower Basin (Chormanski et al., 2009b). The hydrodynamic module of the DSS is used as a tool for studying the relation between flood characteristics and riparian ecosystems including prediction of the ecosystem changes due to human management and climate changes.

10. Conclusion

Establishing the DSS in the BNP has increased awareness of the value of information for management purposes. This is specially important for developing of management and conservation plans as well as for preparing the application for different financial grants supporting conservation measures.

The design of the modern DSS results from the process of implementation of the EC INSPIRE Directive, under which such tools as Arc GIS Server have arisen. Implementation of new technologies has and will continue to further accelerate the process of collecting and sharing data. Moreover, the DSS will have an impact on efficient data collection and use i.e. increasing the level of accuracy of analysis and reduce their costs by optimizing the efficiency. Running the geoportal allowed the wider community to participate in the construction of the DSS and will likely improve the quality of scientific studies and projects performed in the Park. It will also encourage scientific institutions to provide the results of modeling in a digital form and will help the Park staff in decision-making in difficult to predict processes.

11. Acknowledgment

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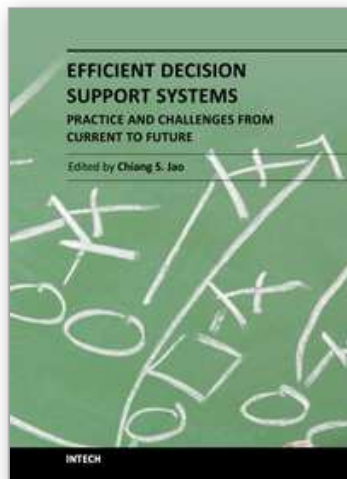
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